

Anomalous Performance of a Near-Infrared Beamsplitter

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

A handwritten signature in cursive script, reading "Michael Zambrana". The signature is written in dark ink and is positioned above the printed name and title.

Michael Zambrana
SMC/AXE

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14. ABSTRACT This document describes an anomaly in the performance of a custom beamsplitter designed and fabricated by one of the major coatings vendors. Specifically, the beamsplitter exhibited a true absorption in the reflective portion of its wavelength range. The absorption was not detected initially by the vendor or the end user because only transmission acceptance tests were performed. This is not uncommon since transmission measurements are frequently easier to perform and because reflectance and transmittance are assumed to be related by the simple formula: $\text{reflectance} = 1 - \text{transmittance}$. This relation does not account for absorption, however, and the problem with this particular beamsplitter was not uncovered until it was installed into its host instrument. The lesson here is to acceptance check any beamsplitter over its full wavelength range in both reflection and transmission, testing it as it will be used.					
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1. Background

The beamsplitter that is the subject of this technical report was an essential part of a spectrograph developed at Aerospace to cover the near-infrared (NIR) wavelength region. It was designed to accommodate two independent spectrographic channels, reflecting light from 0.8–1.35 μm , transmitting light from 1.4–2.5 μm , and transitioning from reflective to transmissive in the interval between 1.35 and 1.4 μm (a region that is largely opaque due to absorption by atmospheric water vapor).

The light incident on a beamsplitter (or any material) can be accounted for by Kirchhoff's equation that relates absorbance (α), reflectance (ρ), and transmittance (τ):

$$\alpha + \rho + \tau = 1.$$

This is simply a statement of conservation of energy—the energy impinging must be transmitted, reflected, or absorbed, and the various portions must total to what is incident. In the case of non-absorbing (lossless) materials the relation simplifies to

$$\rho + \tau = 1.$$

Tacit in design and fabrication of many coated optics is the assumption that over the operational range light is either reflected or transmitted but not absorbed. Under this assumption a beamsplitter can be completely characterized by a transmission measurement alone. In practice, this may considerably simplify testing since reflectance measurements frequently involve more elaborate preparations and cumbersome geometries. This was the course followed for the beamsplitter under discussion—we describe below the problems that resulted.

2. The Beamsplitter

Figures 1 and 2 show the theoretical performance of the beamsplitter as designed.

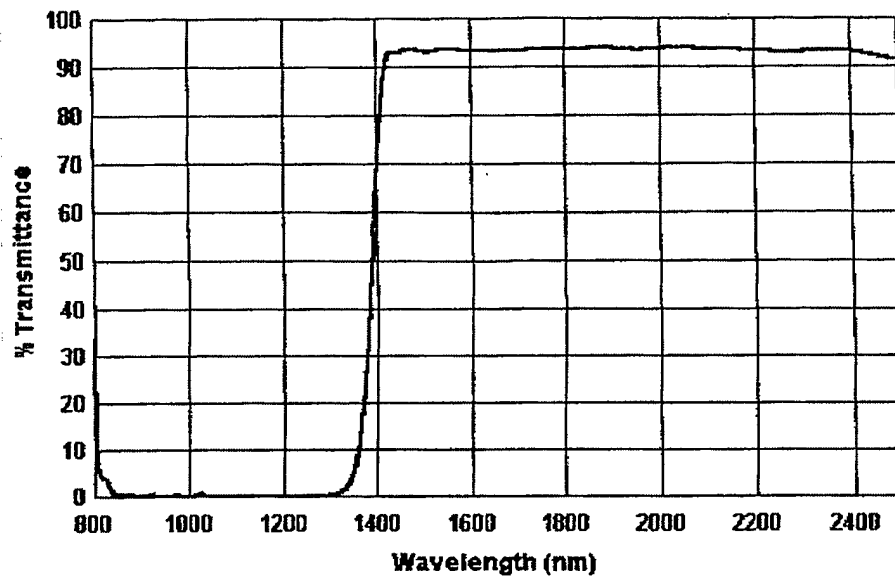


Figure 1. Predicted transmittance from the beamsplitter design. Note that the predicted transmission is very close to 1 – reflectance shown in Figure 2.

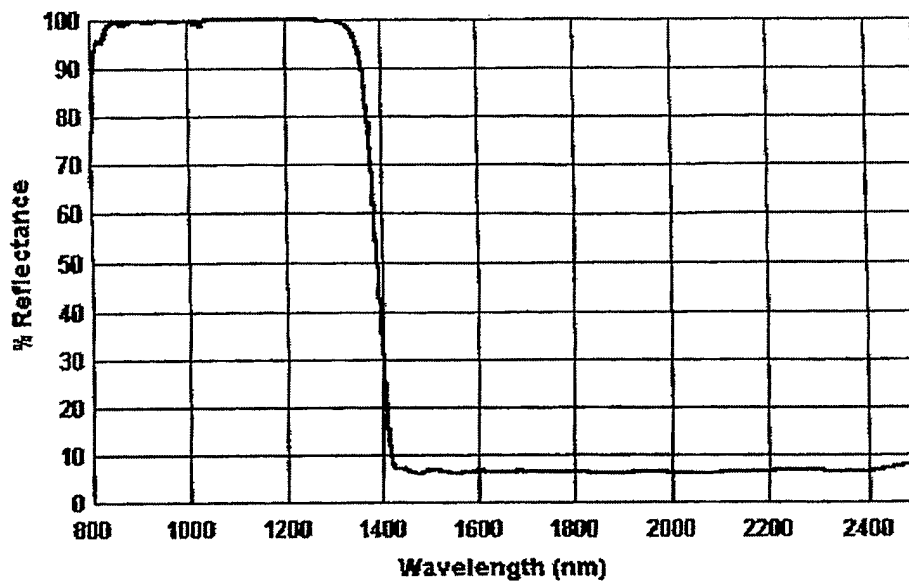


Figure 2. Predicted reflectance from the beamsplitter design. Note that the predicted reflectance is very close to 1 – transmittance shown in Figure 1.

What can be seen is that the reflectance and transmittance are very nearly given by the lossless form of Kirchhoff's equation, that is $\rho + \tau = 1$. Moreover the performance is fairly close to ideal. The reflectance is nearly 100% for almost all of the 0.8–1.35 μm range (800–1350 nm), and the beamsplitter switches rapidly from reflecting to transmitting in the 1.35–1.40 μm interval. Only the performance beyond 1.4 μm is significantly less than optimum, showing a spectrally flat reflectance of ~7% that comes at the expense of the desired transmittance. Expectations for the actual fabricated beamsplitter were for slightly reduced performance since the theoretical design does not account for deviations in the thickness of the deposited layers nor in the broadband anti-reflective coating on the reverse side of the substrate that improves the transmission beyond 1.4 μm .

The beamsplitter, as first built and delivered, had the transmissive and reflective properties displayed in Figures 3 and 4.

From Figure 3 it can be seen that the transmittance behaved as expected from the predicted performance. Unfortunately, transmittance was the only parameter measured, both by the vendor before shipping, and by Aerospace personnel upon receipt. The reflectance measurement of Figure 4 was not acquired until after the beamsplitter had been installed into the spectrograph. The anomalous behavior is the unwanted oscillations in the reflectance in the interval 0.85–1.05 μm . Because there are no corresponding features in the transmittance curve, these features signify true absorption by the beamsplitter.

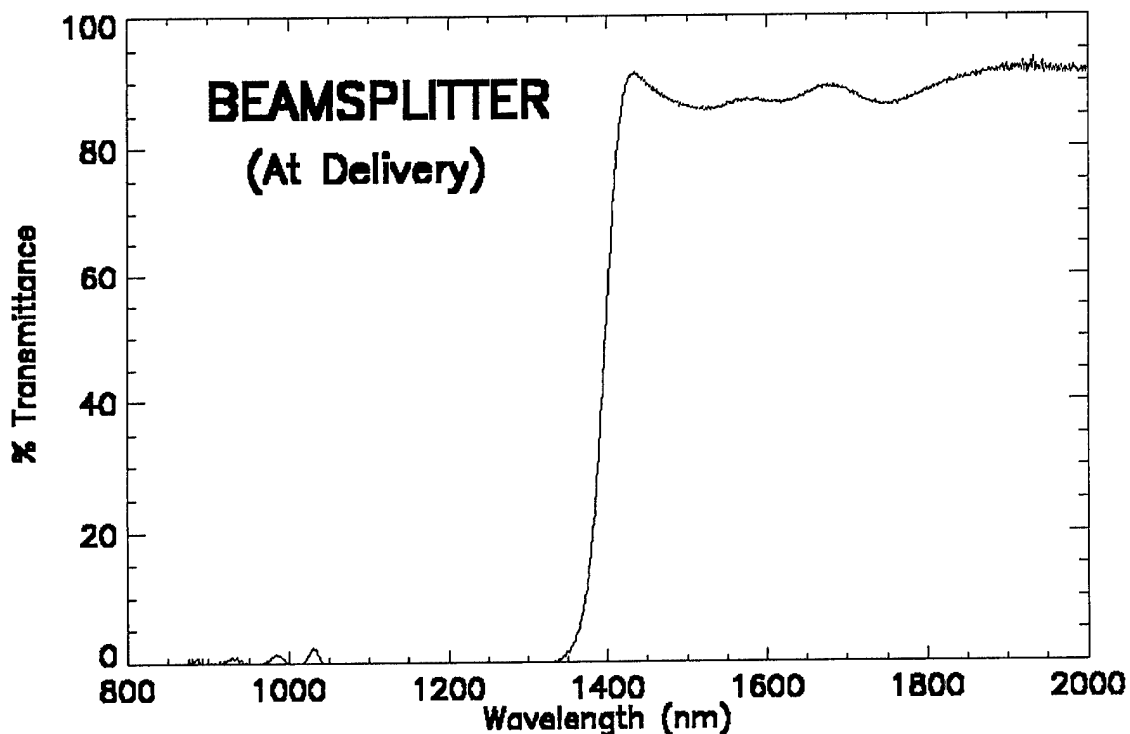


Figure 3. Measured transmittance of the beamsplitter as delivered. Note that this is very close to the theoretical transmission; there is no evidence of any anomaly apparent.

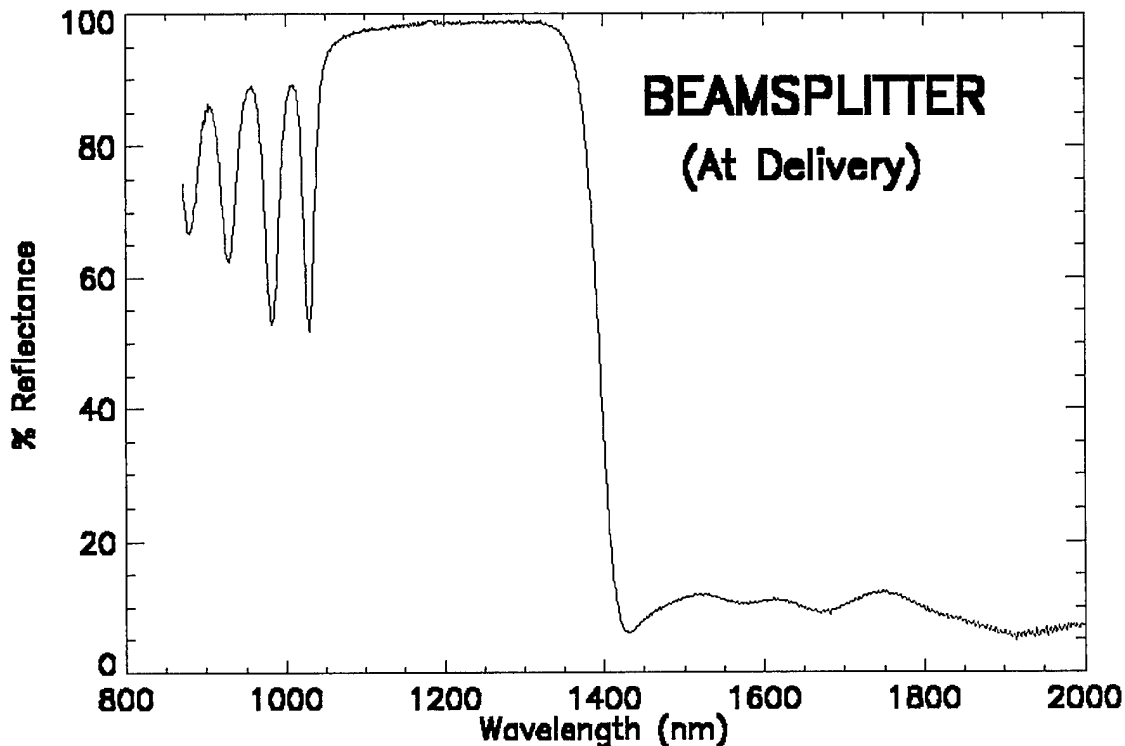


Figure 4. Measured reflectance of the beamsplitter as delivered. The anomalous behavior of the beamsplitter is the absorption features between 0.9 μm and 1.0 μm . The absence of matching features in the transmission spectrum (Figure 3) indicates these are true absorptions. Note that the reflectance is relative to spectralon rather than absolute. However, the reflectance of spectralon is believed to be >99% over this wavelength range.

What was so unexpected about these features, and the reason for the assumption that the lossless form of Kirchhoff's equation was applicable and that beamsplitter performance could be verified by measuring transmittance only, is that none of the materials used in the fabrication of the beamsplitter exhibit absorption in the near-infrared. These included the substrate (sapphire) and the high-index (Nb_2O_5) and low index (SiO_2) coating materials. The designer of the coating (at the vendor) thought that there may have been contamination by water vapor of one or more of the layers. However, a subsequent effort to drive off this water through a bake-out procedure failed so we cannot confirm that this was the problem.

The problem was eventually resolved by adding an additional layer to the coating. The transmittance and reflectance that resulted are illustrated in Figures 5 and 6.

As can be seen from Figure 6, the oscillations between 0.85 and 1.05 μm are gone. However, the downside is that that additional layer added an unwanted reflection around 1.5 μm , reducing the light transmitted to the red channel of the spectrograph. If the beamsplitter has been screened for reflectance upon the initial reception, and thus never passed the acceptance testing, it is probable that the part may have been stripped and recoated from scratch. A superior beamsplitter would have resulted.

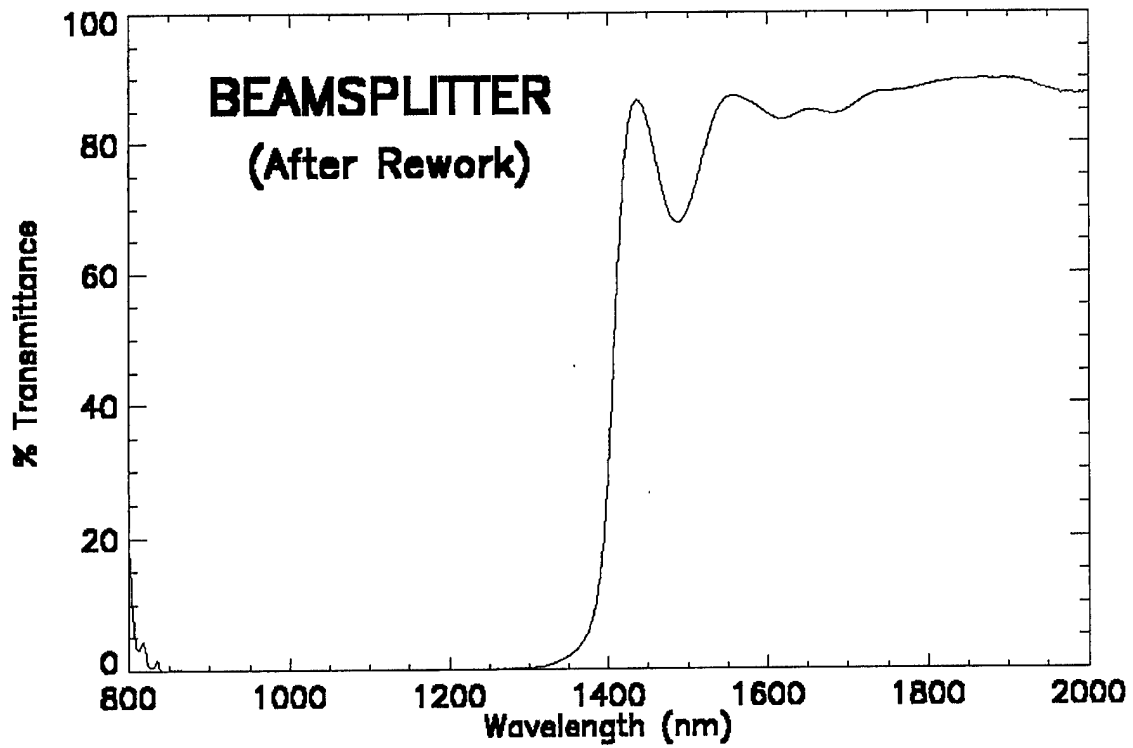


Figure 5. Measured transmittance after recoating.

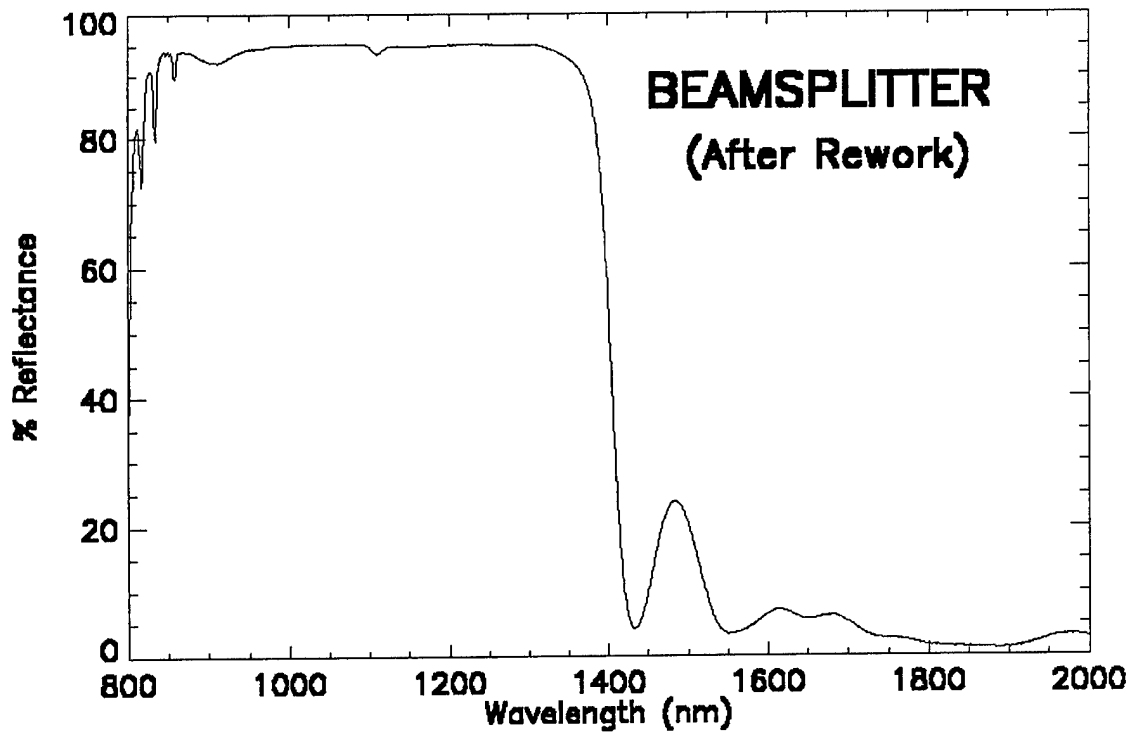


Figure 6. Measured reflectance after recoating.

3. Summary

This document has reported on an entirely unexpected but detrimental absorption exhibited by a beamsplitter that was commissioned for a research spectrograph operating in the near-infrared. This anomalous behavior would have been detected by a more rigorous testing program, both by the vendor and here at Aerospace. It is recommended that any beamsplitter purchased have *both its transmittance and reflectance* measured over the entire wavelength region for which it will be used.

LABORATORY OPERATIONS

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